Not Your Ordinary Traumatic Brain Injury: A Review of Electrical Shock Injury for Forensic and Clinical Neuropsychological Practice

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Disclosures

- Any opinions, findings, conclusions or recommendations expressed are those of the presenters.
- No conflicts of interest to disclose

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Workshop Overview

I. The Basics of Electrical Injury (EI)
II. EI in Comparison to Traumatic Brain Injury
III. Assessment of Performance and Symptom Invalidity in EI
IV. Factors that Influence Neuropsychological Function after EI
V. EI Myths
VI. Concluding Thoughts

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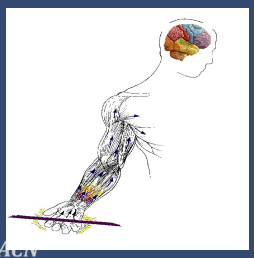
Electrical Shock Injury in The United States



Many electrical accidents go unreported, so the true incidence is difficult to estimate. In the United States, the American Burn Association (*www.ameriburn.org*) estimates 4400 people are injured in electrical accidents and 400 others die from electrocutions each year, which are mostly work-related (mining, electrical work, and construction).

American Burn Association (2016)

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EI Deaths ("Electrocution") by Age Group 1980-1992

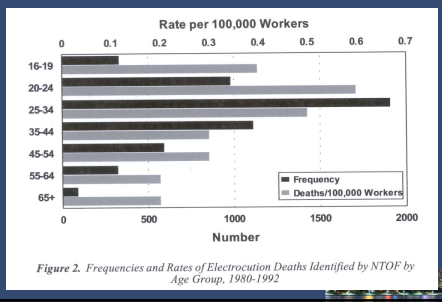

Figure 2. Frequencies and Rates of Electrocution Deaths Identified by NTOF by Age Group, 1980-1992

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Electrocution by Occupation

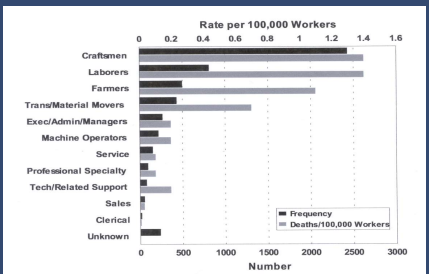

Figure 4. Frequencies and Rates of Electrocution Deaths Identified by NTOF by Occupation, 1980-1992

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Failure to Maintain Correct Safety Practices

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Nomenclature Matters:

Electrocution vs. Electrical Injury

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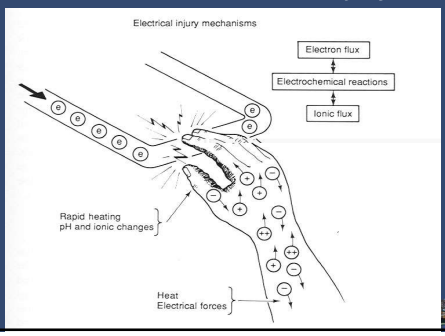
What is an Electrical Injury?



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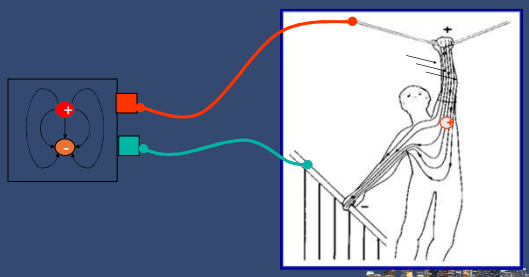
Basics of Electrical Shock Injury



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"Entry" and "Exit" Wounds ??

For 60 Hz a.c. current all wounds are entry and exit wounds

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Voltage vs. Amperage

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Mechanisms of Electrical Injury

- Thermoelectric (Joule) Heating Effect
- Direct Effect of Electrical Current
  - Mechanical Contact
  - Electroporation
- Anoxic Injury Due to Disturbance of the Heart's Electrical Conduction
- Secondary Head Injury/Blast Injury
- *Disconnection of PNS to CNS?*

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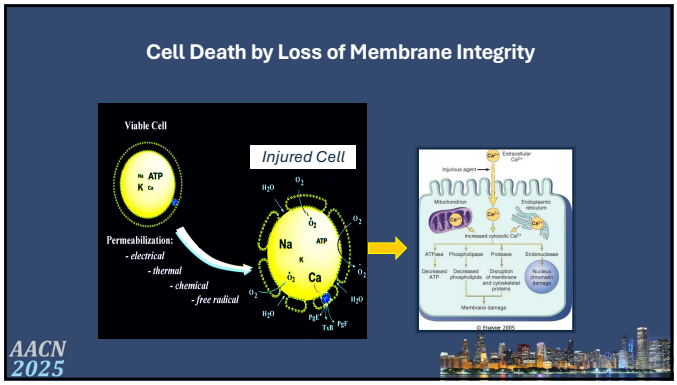
Cell Death by Loss of Membrane Integrity
Viable Cell
ATP
Injured Cell
Permeabilization:
- electrical
- thermal
- chemical
- free radical
Na
K
Ca
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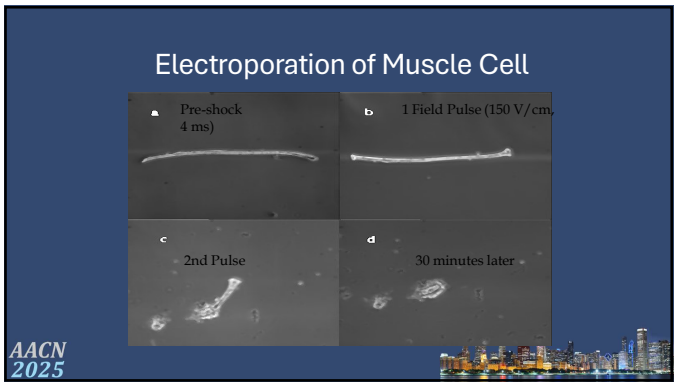
Electroporation of Muscle Cell
a
Pre-shock
4 ms)
b
1 Field Pulse (150 V/cm,
c
2nd Pulse
d
30 minutes later
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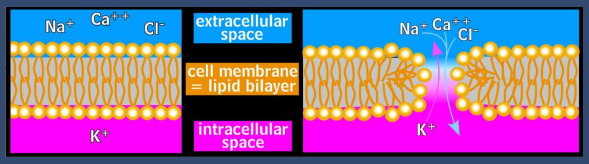
Electroporation in the Peripheral Nervous System



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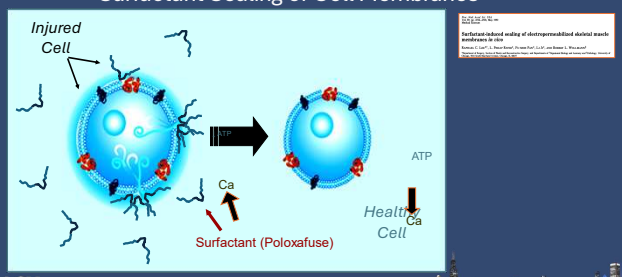
Surfactant Sealing of Cell Membranes



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Electrical Injury Research Program

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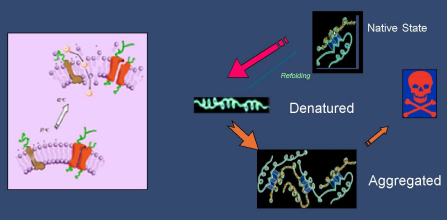
Thermal Injury



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Thermoelectric (Joule) Heating Effect

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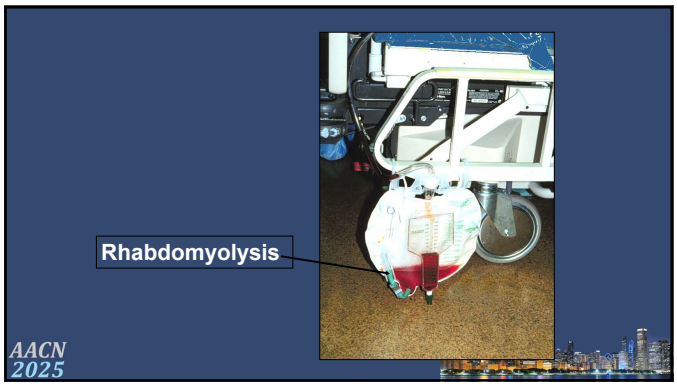

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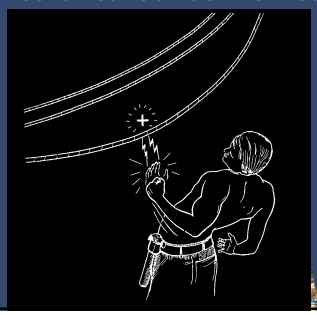
Electric Arc Injury:
Mechanical Contact NOT required



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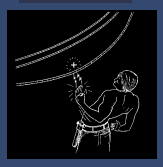
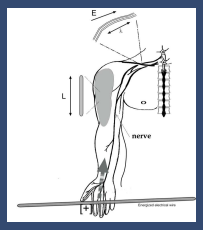
Electroporation of Nerves Responsible for Proprioception

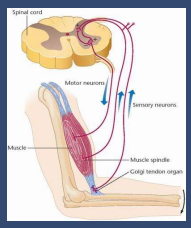
Pathophysiology



Electrical Shock



Nerve and Muscle Injury



Altered proprioception

Peripheral Nerve Compression Associated with Low-Voltage Electrical Injury without Associated Significant Cutaneous Burn

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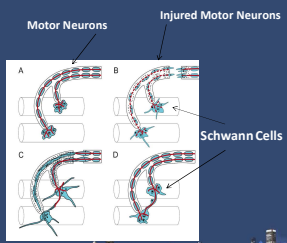
Injured Motor Neurons Do Not Regenerate Perfectly

Neuron, Vol. 14, 125–132, January, 1995, Copyright © 1995 by Cell Press

Schwann Cell Processes Guide Regeneration of Peripheral Axons

Young-Jin Son and Wesley J. Thompson



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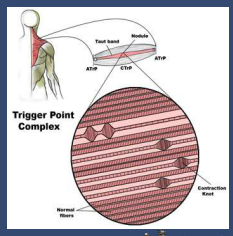
Painful Muscle Trigger Points Result from Imbalance and Dyscoordination



Central or peripheral neuronal injury can lead to altered CNS function.

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Mechanisms of Electrical Injury

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Does this mean no significant EI has occurred?

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The origin of cognitive impairment is multifactorial*

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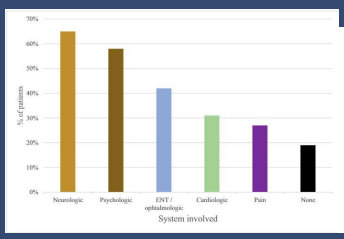
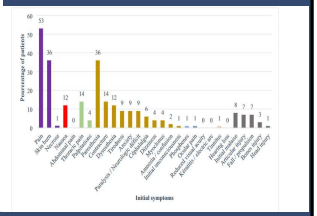
Background: EI is a Multi-System Injury





Chauveau et al., 2021

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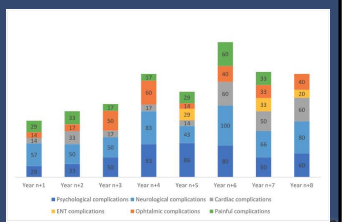
Symptom Complications across Time

- EI treatment does not end after rehabilitation from burn unit.
- Treatment may take the course of years and continuous management of common injury factors are necessary.
- Understanding etiology of various symptoms is necessary to improve treatment recommendations and outcomes (return to work).



Chauveau et al.,2021

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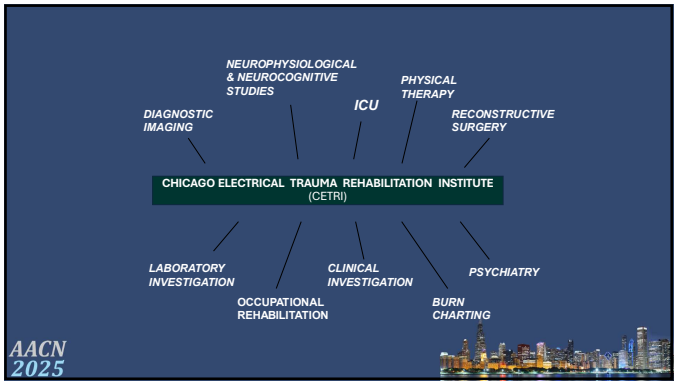
NEUROPHYSIOLOGICAL & NEUROCOGNITIVE STUDIES
PHYSICAL THERAPY
ICU
DIAGNOSTIC IMAGING
RECONSTRUCTIVE SURGERY
CHICAGO ELECTRICAL TRAUMA REHABILITATION INSTITUTE
(CETRI)
LABORATORY INVESTIGATION
CLINICAL INVESTIGATION
PSYCHIATRY
OCCUPATIONAL REHABILITATION
BURN CHARTING
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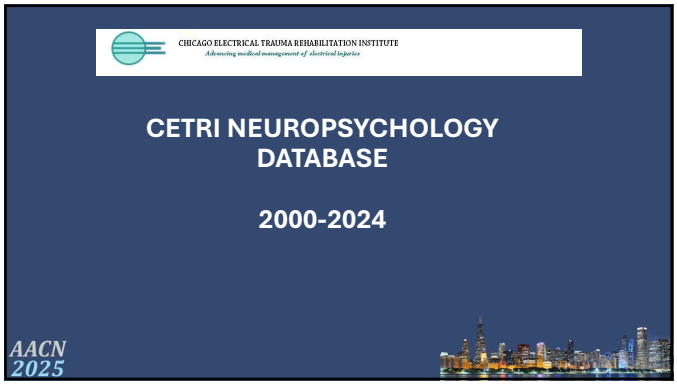
CHICAGO ELECTRICAL TRAUMA REHABILITATION INSTITUTE
Advancing medical management of electrical injuries
CETRI NEUROPSYCHOLOGY DATABASE
2000-2024
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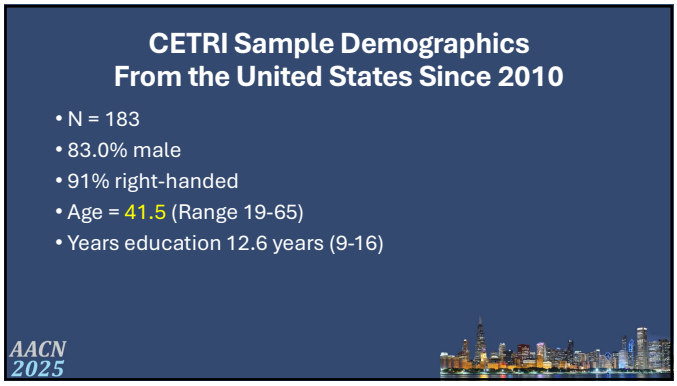
CETRI Sample Demographics From the United States Since 2010
• N = 183
• 83.0% male
• 91% right-handed
• Age = 41.5 (Range 19-65)
• Years education 12.6 years (9-16)
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EI Sample Demographics

- Caucasian 84%
- Hispanic 7%
- African American 6%
- Other/Biracial 2%

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Type of Injury

- Electrical shock: n = 121 (95.0%)
- Lightning strike: n = 6 (5.0%)
- Contact: n = 91 (78%)
- Flash/Arc: n = 26 (22%)

- Work-Related n=147 (80%)
- Litigation n=145 (80%)

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CETRI Patient Characteristics

- Contact burns 45.7%
- Secondary traumatic brain injury (TBI) 6.5%
- Loss of consciousness 46.6%
- Hospitalized 61.9%
- Surgery 31%
- Cardiac arrest 5.5%

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Key Demographic Issues

- Prior psychiatric history: n = 19 (18.8%)
- Prior neurological history: n = 19 (18.8%)

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What are common symptom complaints after EI?

- Cognitive and emotional complaints common but not specific to EI
- May not be apparent acutely; onset may be delayed and course prolonged

	EI (*n*=63)	Controls (*n* =22)	*p*
Concentration	49%	0%	.0001
Word Finding	49%	18%	.01
Slower thinking	46%	9%	.004
Memory Problems	44%	18%	.05
Distracted	43%	14%	.02
Hard to think clearly	39%	0%	.001

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Common Complaints Independent of Severity of Physical Injuries

- "Its not that I can't do things, it just takes me longer"
- "My brain feels like its on screen saver"
- "What was automatic is no longer automatic"

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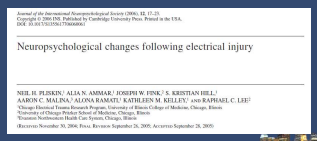
What are the Cognitive Effects of EI?

- 29 EI, 29 healthy electricians
- Matched by estimated pre-injury IQ
- No TBI as part of the injury
- Must have passed symptom validity testing



Neuropsychological changes following electrical injury

NEIL H. PLISKIN,[1] ALIA N. AMMAR,[1] JOSEPH W. FINK,[2] S. KRISTIAN HILL,[1] AARON C. MALINA,[1] ALONA RAMATI,[1] KATHLEEN M. KELLEY,[1] and RAPHAEL C. LEE[2]

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Neuropsychological Findings in EI

Pliskin et al. (2006)

Domain[1]	Measure	Group means/Standard deviation[2] EI patients		Electrician controls		F	df
Attention and Mental Speed		−.75	(.75)	.00	(.70)	15.34	1,56***
	Trail Making Test: Part A time	30.93	(11.76)	23.59	(7.96)	8.15	1,56**
	Trail Making Test: Part B time	70.83	(23.81)	57.97	(24.83)	5.95	1,56**
	Stroop Test: Word	91.76	(16.86)	106.34	(16.55)	7.43	1,56**
	Stroop Test: Color	68.55	(16.08)	78.93	(11.84)	5.72	1,56*
	WAIS-R: Digit Symbol	48.45	(11.47)	58.86	(11.53)	11.89	1,55***
Working Memory		−.09	(.91)	.00	(.68)	.20	1,56
	PASAT: Trial 1	37.00	(11.54)	41.52	(12.59)	NA	
	WAIS-R: Digit Span	16.03	(3.78)	16.34	(3.03)	NA	
Verbal Memory		−.26	(.77)	.00	(.73)	1.77	1,56
	CVLT: Trial 5	12.35	(2.50)	12.72	(2.35)	NA	
	CVLT: Long Delay Free	11.14	(2.99)	12.07	(3.15)	NA	
	WMS-R: Logical Memory % Retained	73.75	(14.95)	79.41	(15.84)	NA	
Visual Memory		.30	(2.24)	.00	(1.01)	.43	1,56
	WMS-R: Visual Reproduction % Retained	84.70	(21.36)	89.93	(9.83)	NA	
Motor Skills		−.63	(1.24)	−.01	(.96)	4.45	1,56*
	Grooved Pegboard: Dominant Completion Time	74.60	(19.75)	65.79	(12.37)	4.07	1,56*
	Grooved Pegboard: Non-Dominant Completion Time	79.95	(22.36)	70.48	(13.15)	4.11	1,56*

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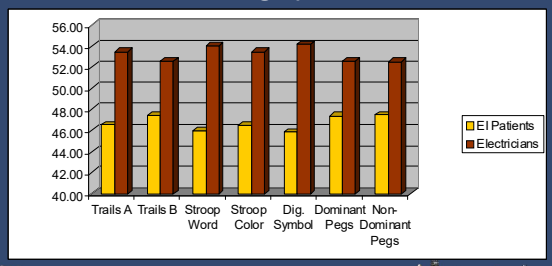
Attention, Processing Speed and Motor Skills



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Key Consideration

- Is there a head (brain) injury in addition to the electrical injury?

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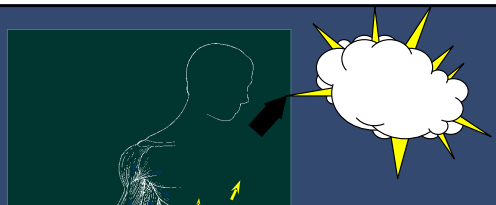

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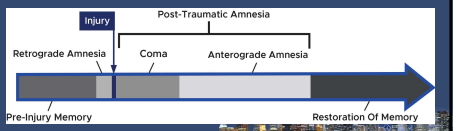
Traumatic Brain Injury (TBI)

- Alteration in mental status
- Loss of consciousness
- Post-traumatic amnesia
- Acute effects seen very early after injury
- Structural damage often evident on imaging (for moderate/severe)

Classification of TBI			
Classification	LOC	GCS	PTA
Mild	<30 min	13-15	<24 hours
Moderate	30min - 24hrs	9-12	1-7 days
Severe	>24 Hours	3-8	>7 Days



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Neuropsychological Outcomes in TBI

- Mild TBI
  - Meta-analytic studies show **no permanent objective** cognitive sequelae
  - Persisting symptom complaints influenced by non-neurological factors
    - Psychiatric/personality factors; litigation; sleep; good old days bias; iatrogenesis
- Moderate-Severe TBI
  - Most rapid recovery typically seen in first 6-12 months
    - Age, cognitive reserve, injury parameters (e.g., PTA length), brain region(s) affected, and volume lost, and medical status can injury prognosis for recovery
  - Some degree of chronic cognitive deficits often persist
    - Learning/memory, processing speed, and complex attention/executive deficits are most common (Dikmen et al., 2009)

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EI is **not** a Typical Closed Head Injury/TBI

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Similarities between EI and TBI

- Age of onset and gender
- EI patients reporting neurocognitive sequelae often have little or no *observable* evidence of acute injury (i.e., they have more ambiguous injuries).
- Similarity and ambiguity of symptom complaints
- Attention/concentration more commonly affected compared to normals

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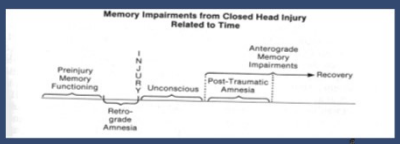
Differences between EI and TBI

- Electrical injury **won't** depend on traditional TBI parameters of LOC or post-traumatic amnesia (PTA)
- Imaging may not be as useful in EI
- Symptom severity and course



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Electrical Injury Severity Cannot Be Considered as a Traditional Traumatic Brain Injury (TBI)

Traumatic Brain Injury

- Loss of consciousness
- Post-traumatic amnesia
- Acute effects seen very early after injury
- Structural damage evident on imaging (moderate/severe)

Electrical Injury

- Loss of consciousness (47%)
- Post-traumatic amnesia (30%)
- Delayed effects often described after injury
- Structural damage NOT typically evidenced on traditional brain imaging

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Neuropsychological Outcomes in EI

- Symptom onset following EI has can be delayed with a range of 1-5 years (Wesner & Hickie, 2013)
- An interesting long-term neuropsychological finding in EI is that some abnormalities (e.g., simple/complex attention) appear to worsen over time from post-acute to chronic injury stages (Aase et al., 2014)
- Why???

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Limitations in Existing EI Neuropsychological Literature

- Reliance on TBI metrics to classify aspects of EI
- Small and restricted samples
- Heterogeneity of outcome measures
  - Subjective complaints vs. objective findings
  - Single measure cognitive outcomes (e.g., MMSE)
- Failure to account for performance/symptom invalidity

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Assessment of Performance and Symptom Invalidity in EI

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EI and Performance Validity

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What is the base rate of performance invalidity among mild TBI examinees?

- Base rates of 17%-58% have been documented (Armistead-Jehle, 2010; Armistead-Jehle & Bucan, 2012; Jak et al., 2015; Larrabee, 2003; Meyers et al., 2011; Proto et al., 2014)
- Differences in setting, evaluation type, and study methodologies contribute to the wide range
  - In general, higher rates of invalidity are expected when external incentive is present
    - 40 +/- 10 (30%-50%) (Larrabee et al. 2009)
    - Mild TBI with no reported external incentive: 21% (Martin & Schroeder, 2021)

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What is the base rate of performance invalidity among EI examinees?

- Poorly defined
  - EI has a much lower incidence rate relative to TBI
    - ~4000 annual cases vs. 2.5 million annual ED visits for TBI
  - More difficult to obtain larger samples of consecutive cases to establish an accurate base rate
- Significant implications for maximizing use of PVTs when evaluation EI examinees
  - PPP & NPP values depend on accurate invalidity base rates in any given examinee population of interest

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Mittenberg et al. (2002)

- Survey study the American Board of Clinical Neuropsychology membership (N=131) of base rates of probable malingering and symptom exaggeration among various presenting conditions
  - Study estimates based on 33,531 annual cases (6,731 personal injury; 3,688 disability; 1,341 criminal; 22,131 medical)
- Among compensation seeking EI examinees, base rates of Probable Malingering or Symptom Exaggeration were:
  - **21.99% (95% CI: 6.02) (reported)**
  - **25.63% (95% CI: 5.54) (adjusted)**

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Bianchini et al. (2005)

- "*Detection and diagnosis of malingering in electrical injury*"
- Examined 11 consecutive EI examinees referred for neuropsychological evaluation
  - All 11 had external incentive (11 worker's compensation; 1 personal injury litigation)
- Used Slick et al. (1999) Malingered Neurocognitive Disorder (MND) criteria
  - PDRT; TOMM; RDS; WAIS Embedded CVLT Embedded; multiple MMPI-2 scales)
  - Most had 1-2 freestanding PVT; 3 embedded PVTs; and 3 MMPI F-scales
- Base rate of invalidity:
  - **64% (9/14 evaluations; 3 reevaluations included)**
    - **Included 8 "probable" MND and 1 "definite" MND**

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Resch et al. (2021)

- "*Establishing the base rate of performance invalidity in a clinical electrical injury sample: Implications for neuropsychological test performance*"
- Examined 101 consecutive EI examinees referred for neuropsychological evaluation from 2002-2018 through CETRI
- At the time of evaluation, 85.1% (n=86) of the sample had active external incentive (i.e., workers compensation, personal injury litigation, or disability benefits)

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Resch et al. (2021)

- 87% Male / 13% Female
- Mean age=43.9 (SD=9.78; range 19-65)
- Mean education 12.5 years (SD=1.57; range 9-16)
- 87% White / 7% Black / 5% Hispanic
- Injury Setting:
  - 76% occupational/workplace
  - 24% domestic setting
- Mean time since injury=27.91 months (SD=18.18; range 1-97)

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Resch et al. (2021)

- Individual PVTs varied across evaluations (~20-year timeframe)
  - PVTs and best practice standards have evolved over the past 2 decades
- All administered at least 1 freestanding PVT (M=1.98; SD=0.65)
  - Dot Counting Test; Rey 15-Item Test; Test of Memory Malingering; Victoria Symptom Validity Test; Word Memory Test
- And multiple embedded PVTs (M=3.18; SD=1.15; range: 0-5)
  - BVMT-R RD; CVLT-II FC; RBANS EI; SCWT Word Reading; RDS
- Mean PVTs administered=5.23 (SD=1.23; range 2-7)

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Resch et al. (2021)

- 89% (n=90) had ≥4 PVTs administered
  - These 90 were retained for analysis
- Of the 11% (n=11) with ≤3 PVTs administered:
  - 6 failed ≥2 PVTs
    - Retained for analysis as "invalid" as additional PVTs would not change validity status
  - Remaining 5 were excluded as indeterminant cases
    - Too few PVTs to reliably conclude that performance was valid

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Resch et al. (2021)

- What about those with 1 PVT failure
  - 50 failed 0 PVTs (valid)
  - 17 failed 1 PVT (none below chance)
  - 29 failed ≥2 PVTs
  - 5 were excluded (indeterminant)
- **29% observed base rate of invalidity**
  - Notably lower than the 85% external incentive/compensation seeking rate
- 1 PVT failures examined via supplemental analyses

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Resch et al. (2021)

Test	0 PVTs Failed *M (SD)*	1 PVT Failed *M (SD)*	≥2 PVTs Failed *M (SD)*
TMT-A	47.57 (10.78)	47.18 (7.57)	33.71 (15.70)
TMT-B	47.67 (9.65)	43.82 (8.34)	35.71 (13.63)
PSI	94.86 (11.21)	91.33 (10.42)	77.00 (12.88)

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Resch et al. (2021)

- No significant differences between 0, 1, or ≥2 PVT failures based on:
  - Any demographic characteristic
  - Premorbid psychiatric history
  - Current depression symptoms (BDI-II)
  - Compensation-seeking status
  - Any injury characteristic
    - "No Let-Go" Response
    - Loss of Consciousness
    - Posttraumatic Amnesia
    - Cardiopulmonary Arrest
    - Thermal Burns
    - Required Hospitalization

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EI & Performance Validity: Summary

- Far less empirical data exists relative to other forensic populations
- Largest study using consecutive EI cases (Resch et al., 2021) as well as professional survey data (Mittenberg et al., 2002) document the base rate of performance invalidity at **~26%-29%**
  - Notably higher than most general clinical populations
  - On the lower end of the 30-50% estimate among mTBI
  - Observed invalidity base rate is notably lower than external incentive rate
  - PVT failure/invalidity does not appear related to injury characteristics

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EI and Symptom Validity

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EI and Symptom Invalidity

- Less defined than performance invalidity rates in EI
- Base rates can be extracted from Bianchini et al. (2005)
  - Used PVTs and SVTs to assess "negative response bias"
  - MMPI-2: F, Fp, FBS
  - 11 examinees with electrical injury
  - 13 MMPI-2s (1 missing data point; 3 repeat evaluations)
  - 8/13 (~61%) had a least 1 MMPI-2 F-scale elevation
    - Of these, 2/13 had 2 F-scale elevations, and 0 had 3
  - Elevations were predominantly on FBS (6) or F (4), not Fp (1)

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Wicklund et al. (2008)

- "*MMPI-2 patterns in electrical injury: A controlled investigation*"
  - Compared MMPI-2 profiles in EI, chronic pain, and mild TBI
  - ~70% of EI sample were involved in litigation at time of evaluation
- Excluded invalid profiles used the following criteria (Graham, 1993; Lee-Halaye et al., 1991)
  - VRIN ≥80T; TRIN ≥80T; L ≥65T; K ≥65T; F ≥100T; FBS ≥30 (raw)
- 35 EI cases were excluded due to invalidity
  - **Absolute Base Rate: 44% (35/79)**
    - Further analysis of type of invalidity was not reported
  - Chronic Pain BR: 29% (6/21); mTBI BR: 16% (3/19)

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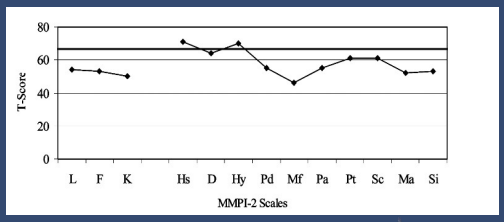
Wicklund et al. (2008)



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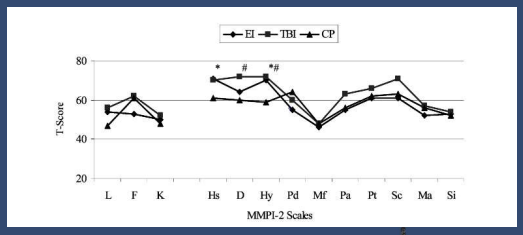
Wicklund et al. (2008)



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Soble et al. (2019)

- "*Examination of the Minnesota Multiphasic Personality Inventory-2-Restructured Form (MMPI-2-RF) validity and substantive scales in patients with electrical injury*"
- Examined base rates of MMPI-2-RF F-scale elevations in EI examinees with valid symptom reporting and cognitive test performance established via independent SVTs/PVTs
  1. Investigated whether electrically injured examinees who endorse bona fide symptoms that are common EI sequelae, but uncommon among general medical patients, may potentially be misclassified by the validity scales as overreporting unusual or noncredible symptoms
  2. Describe MMPI-2-RF clinical profiles among valid EI examinees

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Soble et al. (2019)

- Starting point: 96 EI patients evaluated from 2002-2018
  - 20 were not administered an MMPI (excluded)
  - 13 did not receive an independent SVT (excluded)
  - 1 excluded due to excessive protocol nonresponding
  - 0 exclusions based on TRIN/VRIN
- Starting point of 62 study participants

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Soble et al. (2019)

- 62 study participants
  - 37 completed the MMPI-2 (rescored) / 25 completed the MMPI-2-RF
  - All were administered at least 1 independent SVT (M=1.79)
  - All were administered 4-7 PVTs (M=5.44)
- Retained as valid if 0 SVT failures **and** ≤1 PVT failure
  - 0 v. 1 PVT fails was negligible (≤2 T-score points) across all 51RF scales
  - Study Invalidity Base Rate: 26% (16/62) - excluded as invalid
- Final Sample: 46 EI examinees

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Soble et al. (2019)

- MMPI-2-RF validity scales had negligible to small correlations with age, education, premorbid psych history, and external incentive
- RF validity scale intercorrelations generally ≤.50
- Effect sizes for Valid vs. Invalid EI examinees
  - VRIN: d=0.02
  - TRIN: d=0.30
  - F-r: d=0.43
  - Fp-r: d=0.22
  - Fs: d=0.43
  - **FBS-r: d=0.83**
  - **RBS: d=0.70**
  - L-r: d=0.45
  - K-r: d=0.08

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Soble et al. (2019)

- Elevation rates on the MMPI-2-RF overreporting scales (valid group)

T-score	F-r	Fp-r	Fs	FBS-r	RBS
	N (%)	N (%)	N (%)	N (%)	N (%)
<70	-	41 (89%)	-	-	-
<79	29 (64%)	43 (94%)	31 (67%)	29 (63%)	23 (50%)
80-99	12 (26%)	3 (7%)	11 (24%)	15 (33%)	19 (41%)
≥100	5 (10%)	0 (0%)	4 (9%)	2 (4%)	4 (9%)
Total with Clinical Elevation	17 (36%)	5 (11%)	15 (33%)	17 (37%)	23 (50%)

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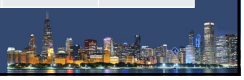

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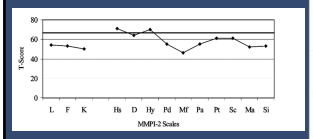
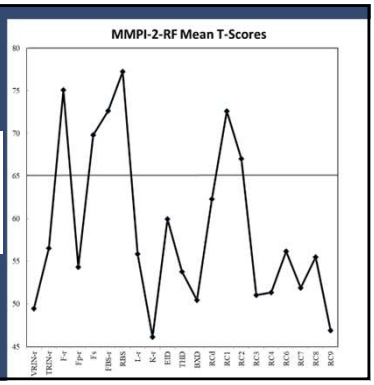
Soble et al. (2019)





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EI & Symptom Invalidity: Summary

- Few studies have examined symptom invalidity base rates among EI examinees & there are limitations among existing studies
  - Differences in SVTs and how symptom invalidity is operationalized
  - Sample size
- Base rate ranges from 26%-61% among existing studies
- Interpretation of "possible overreporting" on some MMPI-2-RF F-scales may be confounded by genuine symptoms that are not rare among individual who sustain EI
  - (e.g., burns, numbness, paresthesias, phantom pain phenomenon)

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Concordance of Performance and Symptom Validity in EI

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Performance and Symptom Validity Concordance

- PVTs and SVTs capture related, but generally nonredundant/nonoverlapping constructs (Larrabee, 2012)
- Strength of relationship between PVTs and SVTs varies considerably by examinee population
  - Robust concordance in some populations
    - Disability claimants (Gervais et al., 2007)
    - MMPI-2-RF RBS scale developed based on those who failed memory PVTs
  - Minimal to modest concordance in other populations
    - ADHD (e.g., Ovsiew et al., 2023)
    - General neuropsychiatric referrals (e.g., DeBoer et al., 2022)

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Obolsky et al. (2022)

- "*Concordance of Performance and Symptom Validity Tests Within an Electrical Injury Sample*"
- 188 consecutive EI referrals from 2001-2021
  - 83 missing an MMPI (excluded)
  - 1 excessive nonresponding (excluded)
  - 10 had fewer than 3 PVTs administered (excluded)

Total Sample: 94 EI examinees

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Obolsky et al. (2022)

- Total Sample: 94 EI examinees
  - Performance Invalidity: ≥2 PVT failures
  - Symptom Invalidity:
    - Determined by the 5 RF overreporting (F-scales)
    - Different symptom invalidity grouping procedures were examined
      - Any Elevation on 1, 2, or ≥3 F-scales
      - Any Definite Overreporting Elevation on 1, 2, or ≥3 F-scales

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Obolsky et al. (2022)

- Any Overreporting Elevations

	Invalid SVT scores (≥1 elevation; *n*=62)	Valid SVT scores (0 elevations; *n*=32)
Invalid PVT scores (≥2 failures)	**21 (22%)**	2 (2%)
Valid PVT scores (≤1 failure)	41 (44%)	**30 (32%)**
	Invalid SVT scores (≥2 elevations; *n*=51)	Valid SVT scores (≤1 elevation; *n*=43)
Invalid PVT scores (≥2 failures)	**16 (17%)**	7 (7%)
Valid PVT scores (≤1 failure)	35 (38%)	**36 (38%)**
	Invalid SVT scores (≥3 elevations; *n*=30)	Valid SVT scores (≤2 elevations; *n*=64)
Invalid PVT scores (≥2 failures)	**10 (10%)**	13 (14%)
Valid PVT scores (≤1 failure)	20 (22%)	**51 (54%)**

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Obolsky et al. (2022)

- Definite Overreporting Elevations

	Invalid SVT scores (≥1 elevation; *n*=28)	Valid SVT scores (0 elevations; *n*=66)
Invalid PVT scores (≥2 failures)	**10 (10%)**	13 (14%)
Valid PVT scores (≤1 failure)	18 (20%)	**53 (56%)**
	Invalid SVT scores (≥2 elevations; *n*=16)	Valid SVT scores (≤1 elevation; *n*=78)
Invalid PVT scores (≥2 failures)	**8 (8%)**	15 (17%)
Valid PVT scores (≤1 failure)	8 (8%)	**63 (67%)**
	Invalid SVT scores (≥3 elevations; *n*=6)	Valid SVT scores (≤2 elevations; *n*=88)
Invalid PVT scores (≥2 failures)	**2 (2%)**	21 (22%)
Valid PVT scores (≤1 failure)	4 (5%)	**67 (71%)**

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Concordance of PVTs and SVTs in EI: Summary

- Some concordance exists between failure on PVTs and failure on SVTs among EI examinees
- The degree of concordance becomes more robust as the number and severity of MMPI-2-RF F-scale elevations increase
- PVTs and SVTs capture related, but nonredundant information regarding validity status among EI examinees
  - They are not interchangeable and should be assessed separately
- Effect(s) of SVT failure on neuropsychological test performance (if any) remains unclear in this population

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Performance and Symptom Validity Assessment in EI: Summary

- EI often exemplifies the blurring between forensic and clinical neuropsychological evaluations
  - Even if clinically presenting, a substantial percentage will have active external incentive
- EI Performance Invalidity Base Rate: ~29%
- EI Symptom Invalidity Base Rate (based on larger studies): 26%-44%
- PVTs/SVTs show some concordance that increases as SVT elevations become more extreme and frequent
  - PVT sand SVTs capture nonredundant information and should be assessed separately

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Workshop Overview

I. The Basics of Electrical Injury (EI)
II. Electrical Injury in Comparison to Traumatic Brain Injury
III. Assessment of Performance and Symptom Invalidity in EI
IV. Factors that Influence Neuropsychological Function after EI
V. EI Myths
VI. Concluding Thoughts

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Neuropsychological Findings/Outcomes in EI

- First, a key distinction
- Most EIs

  vs.
- Special Cases
  - Lightening Strikes
  - EI with Direct Point of Contact to the Head
  - EI Resulting in Prolonged Cardiopulmonary Arrest

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Neuropsychological Findings in EI

- Effects of EI on the peripheral nervous system are better understood than potential CNS effects
- ~40% of those with EI will experience a complex constellation of ongoing cognitive, emotional/behavioral, and physical complaints (Piskin et al., 1998)
  - Neuropsychologists play a key role in objectively characterizing the validity, nature, extent, and contributing factor(s) if these complaints

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Neuropsychological Findings in EI

- Is there a pathognomonic EI neuropsychological profile?
  - No
- When present, neuropsychological abnormalities typically are mild and nonspecific (Piskin et al., 1998; 2006)
  - Attention
  - Speed
  - Motor Skills (can be confounded by effects of peripheral injuries)
- Undetected performance invalidity confound is an important consideration for older studies

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Neuropsychological Findings in EI

- Neuropsychological abnormalities that are **not** typical of EI (Piskin et al., 1998; 2006)
  - Global Neuropsychological Dysfunction
  - Severe Neurocognitive Deficits
  - Focal Impairment
  - Degradation of Intellect or Core Abilities
  - Amnestic Memory Deficits (cases of anoxia excluded)
- Parameters of the actual EI (e.g., high vs. low voltage) do not significantly explain neuropsychological presentation

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Are there unique neuropsychological sequelae of EI?

- Many prior EI studies were cross-sectional or made comparisons to healthy/normal controls
- Leaves the question of how cognition in EI differs from other trauma-exposed and psychopathological populations unanswered
- Best controlled study addressing this issue came in 2021

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Neuropsychological functioning in electrical injury survivors: A comparison to combat-exposed veterans with and without posttraumatic stress disorder (Resch, 2021)

- 35 individuals with EI vs. 24 veterans with PTSD and 25 veterans without PTSD (trauma-exposed control group).
- All participants had objectively valid test performance (per PVTs)
- Examined processing speed, immediate and delayed memory, and executive function cognitive composite domain scores
- Group differences examined between the individuals with EI compared to veterans with and without PTSD across each cognitive domain

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Table 3. Composition of the cognitive domains

Cognitive Domain	Neuropsychological Test
Processing speed	Coding
	Symbol Search
Immediate memory	BVMT-R Trials 1-3 Learning
	CVLT-II Trials 1-5 Learning
Delayed memory	BVMT-R Delayed Recall
	CVLT-II Long-Delay Free Recall
Executive function	SCWT Color-Word
	Trails B
	WCST-64 Perseverative Responses

Note. Citations provided in the method section. BVMT-R: Brief Visuospatial Memory Test-Revised; CVLT-II: California Verbal Learning Test-2nd Edition; SCWT: Stroop Color-Word Test; WCST-64: Wisconsin Card Sorting Test – 64 Card Version.

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Table 5. Cognitive performance stratified by group

	EI (n = 35)	PTSD (n = 24)	TEC (n = 25)
Domain	*M (SD)*	*M (SD)*	*M (SD)*
Processing Speed[1]	-0.40 (0.72)	-0.08 (0.61)	0.64 (1.07)
Immediate Memory[1]	-0.34 (0.77)	0.03 (0.84)	0.44 (0.84)
Delayed Memory[1]	-0.34 (0.78)	-0.05 (0.76)	0.53 (0.74)
Executive Functions[1]	-0.26 (0.63)	-0.07 (0.49)	0.45 (0.75)
Test	*M (SD)*	*M (SD)*	*M (SD)*
Coding[2]	8.17 (2.05)	9.25 (1.80)	11.04 (2.98)
Symbol Search[2]	9.40 (2.38)	10.08 (2.39)	12.40 (3.79)
BVMT-R Trials 1- Learning[3]	39.83 (10.93)	42.00 (12.96)	48.88 (10.71)
CVLT-II Trials 1-5 Learning[4]	48.06 (9.66)	54.08 (9.25)	56.72 (11.31)
BVMT-R Delayed Recall[3]	44.40 (12.85)	44.33 (14.04)	57.32 (11.06)
CVLT-II Long-Delay Free Recall[5]	-0.34 (0.95)	0.23 (0.87)	0.46 (0.96)
SCWT Color-Word[6]	47.29 (9.26)	50.83 (8.66)	54.72 (8.68)
Trails B[7]	47.34 (8.23)	47.43 (7.42)	55.20 (14.84)
WCST-64 Perseverative Responses[6]	44.63 (7.36)	45.96 (5.49)	50.12 (12.69)

Note. PTSD group (n = 23) for executive function domain and SCWT due to exclusion of an outlier. BVMT-R: Brief Visuospatial Memory Test-Revised; CVLT-II: California Verbal Learning Test-2nd Edition; EI: electrical injury; PTSD: posttraumatic stress disorder; SCWT: Stroop Color-Word Test; TEC: trauma-exposed controls; WCST-64: Wisconsin Card Sorting Test – 64 Card Version.

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EI vs Veterans with and without PTSD

- EI group was fairly similar from the veterans with CAPS-confirmed PTSD, differing only on select measures of processing speed and verbal memory.
- Cognition in EI survivors is generally comparable to that of combat-exposed veterans, suggesting that PTSD may play an important role in identifying patients at risk of persistent cognitive sequalae following EI
- Subtle cognitive difficulties demonstrated by survivors of EI are beyond what would be expected based on mere trauma exposure and may show nuanced differences from those who develop PTSD from other forms of trauma

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Neuropsychological Findings in EI: Summary

- *"The difficulty with recognizing and diagnosing these long-term sequelae of electrical injury is that the complaints are often not proportional to the degree of acute injury, the electrical current or voltage, or the current's pathway through the body. Complicating this is the lack of a pathophysiologic explanation for complaints that are persistent and occasionally progressive, but which are vague, nonspecific, and prevalent in the general population"*

(Wesner & Hickie, 2013)

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Best Practices for Diagnosis and Intervention in EI

- EI patients often show mild, nonspecific neuropsychological dysfunction
- The underlying reason for these neuropsychological difficulties is not always clear and likely is multifactorial
- Etiology(ies) of cognitive issues may fall outside CNS pathology

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Direct Effects of Electrical Exposure
Pain
Sleep
Trauma-Emotion Regulation
Medications
Identity-Adjustment Issues

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Understanding Cognitive Impairments in EI – Chronic Pain

- Chronic pain is frequently reported in pts with EI
- Research with chronic pain pts has documented a relationship between pain, mood, and cognition in this population

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Table 3. *Electrical Injury and Chronic Pain Neuropsychological and Mood Test Scores*

	Electrical Injury Group ($n = 52$)	Chronic Pain Group ($n = 52$)	Results of Group Comparisons		
	M (*SD*)	*M* (*SD*)	*F*	*p*	η_p^2
Pain P3 Somatization Scale	49.69 (9.10)	48.48 (6.47)	.61	.436	.006
Attention/Processing Speed: TMT-A Completion Time	35.52 (14.87)	36.50 (12.47)	.13	.716	.001
Verbal Memory: CVLT-II Long Delay Free Recall	9.10 (3.57)	8.85 (4.24)	.11	.746	.001
Executive Functioning: WCST Number of Categories	4.67 (1.78)	4.48 (1.80)	.30	.585	.003
Depression: BDI-II Total	22.13 (10.17)	15.56 (11.32)	9.66	.002	.087

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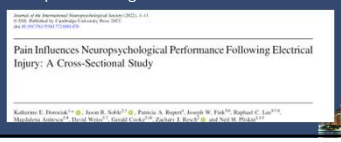
Pain and Mood Affect Cognition after Electrical Injury

I. After adjusting for opioid pain and psychotropic medication use, higher pain levels were associated with poorer attention/processing speed and verbal memory performance among EI patients.

II. While depression is significantly correlated with pain, depression does mediate the relationship between pain and cognition in EI patients.

III. When comparing the EI and chronic pain patients, the relationship between pain and cognition is similar for both clinical groups.


Pain Influences Neuropsychological Performance Following Electrical Injury: A Cross-Sectional Study

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EI & Chronic Pain

- Post-EI pain complaints are common and reported among ~50% of survivors
  (Bryan et al., 2005; Primeau, 2005; Ramatlet al., 2009; Wesner & Hickle, 2013)
- Pain complaints often appear disproportionate to visible injury
  - Differences in skin vs. underlying muscle tissue's resistance to electricity
- Pain significantly influences neuropsychological outcomes

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EI & Chronic Pain

- Dorociak et al. (2022)
  - Examined effects of pain among EI examinees with a chronic pain comparison sample
- Take Homes:
  - Higher pain levels were associated with poorer attention/processing speed and executive functioning performance among EI examinees
  - Depression significantly correlated with pain and mediated the relationship between pain and attention/processing speed among EI examinees
  - Relationships between cognition and pain were similar for EI and chronic pain groups
  - **Pain impacts mood and cognition and is a critical neuropsychological consideration when evaluating EI examinees**

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Key Point:

EI patients' pain experience may influence cognitive and emotional functioning.

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Understanding Cognitive Impairments in EI: Emotional Symptoms

- Difficulties may be due to increased emotional complaints

	EI (n=63)	Controls (n =22)	*p*
Stress/Anxiety	49%	14%	.007
Sadness/Depression	48%	14%	.01
Attitude Change	41%	9%	.02
Anger/Temper	30%	5%	.03

Pliskin et al. 1998

- PTSD and depression also linked to poorer memory performance (Grigorovich et al. 2013; Ammar et al. 2006)

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Understanding Emotional Changes after EI

- Ramati et al. (2009) study of 86 EI pts across three phases of recovery: acute, post-acute, and long-term
- 78% of the total sample warranted a psychiatric diagnosis.

Diagnoses in EI patients	Acute (≤3 mos) (n=26)	Post-acute (>3 to ≤24 mos) (n=27)	Long-term (>24 mos) (n=32)
With Psych Diagnosis	65%	85%	81%
Without Psych Diagnosis	35%	15%	19%

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Understanding Cognitive Impairments in EI – Emotional Symptoms

	Acute (≤3 mos) (n=26)	Post-acute (>3 to ≤24 mos) (n=27)	Long-term (>24 mos) (n=32)
Depression	1(4)	**10(37)**	4(13)
PTSD	4(15)	5(19)	4(13)
Anxiety disorder	2(8)	0	1(3)
Depression + PTSD	4(15)	3(11)	**11(34)**
Depression + Anxiety	0	1(4)	3(9)
Somatization	0	1(4)	2(6)
Adjustment disorder	**5(19)**	1(4)	0
Mental Disorder NOS	1(4)	2(7)	3(3)

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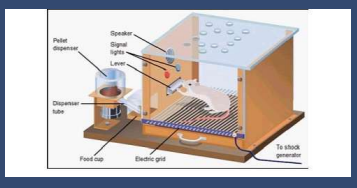
Posttraumatic Stress Disorder (PTSD)



Animal Fear-Conditioning Electrical Shock Paradigm

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Retrospective Cohort Study Evaluating EI Admissions Between 1998 and 2015 in Canada: Acute Symptoms

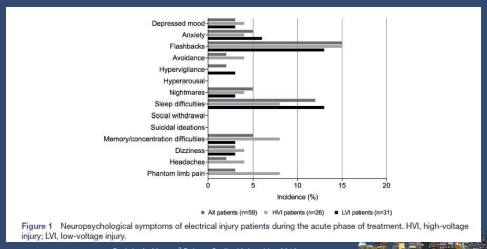

Figure 1 Neuropsychological symptoms of electrical injury patients during the acute phase of treatment. HVI, high-voltage injury; LVI, low-voltage injury.

Radulovic, Mason,[2] Rehou, Godleski, Jeschke, 2019

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Retrospective Cohort Study Evaluating EI Admissions Between 1998 and 2015 in Canada: Delayed Symptoms

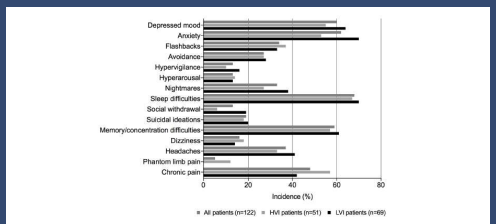

Figure 2 Neuropsychological symptoms of electrical injury patients during the long-term phase of treatment. HVI, high-voltage injury; LVI, low-voltage injury.

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Two Examples

- 43-year-old firefighter
- 47-year-old mine foreman and EMS

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Key Point:

EI patients experience psychiatric changes and particularly problems with emotion regulation. These symptoms may exacerbate cognitive difficulties.

*These symptoms are not a character flaw or the sign of a weak personality. They are symptoms of emotional trauma and maybe more.

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What We Know About the Neuropsychology of Electrical Injury After Two Decades

- EI results in cognitive dysfunction in many survivors
- EI survivors develop changes in mood and emotional regulation, despite most having no prior history of psychiatric difficulties
- Cognitive and emotional changes remain a major source of disability that affect patients years later.
- The lack of clarity in CNS correlates/brain contributions inhibits development of more effective post-injury interventions.

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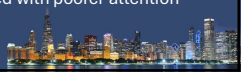
Psychological Findings/Outcomes in EI

- Psychopathology can emerge acutely or post-acutely (Bieringet al., 2021)
- Rates of psychopathology among EI examinees (Ramtietal., 2009)
  - 65% acutely (≤3 months)
  - 85% post-acute (3-24 months)
  - 81% chronically (≥24 months)
- PTSD and Depression are the most prevalent post-EI psychological disorders
- Increased depressive symptoms was associated with poorer attention performance (Aaseetal., 2014)



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EI & PTSD

- EI events often will qualify as a PTSD Criterion A Event
  - "*Exposure to **actual or threatened death**, **serious injury**, or sexual violence*"
- Many EIs occur in the workplace, which presents challenges some unique challenges if PTSD is present
  - Regular/recurrent exposure to stimuli that trigger intrusive symptoms
  - Avoidance may be more persistent
  - Delayed onset – Sxs may not become obvious until return to work looms
- Early identification and evidence-based treatment is critical
- **Are observed neuropsychological alterations in EI distinct from PTSD?**

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Phenomenology of PTSD in EI

Obolsky (2024)

Table 1. Demographic Variables and Mean Scores Groups with SVT Cut-offs

	EI	mTBI/PTSD Group	CE			
	n= 27 *M (SD)*	n= 23 *M (SD)*	n= 54 *M (SD)*	*p* value*	η_p^2	Post hoc
Age (years)	45.37 (8.99)	35.73 (6.66)	34.90 (8.55)	<.001	.231	EI>CE, TBI/PTSD
Education (years)	13.00 (2.78)	14.91 (2.13)	15.05 (2.4)	.002	.118	EI<CE, TBI/PTSD
	n (%)	*n* (%)	*n* (%)	*p* value**		
Sex				.044		
Male	24 (89%)	22 (96%)	40 (75%)			
Female	3 (11%)	1 (4%)	14 (25%)			
Race						
Caucasian	20 (74%)	8 (35%)	20 (35%)	.002		
Black	3 (11%)	11 (48%)	16 (30%)			
Hispanic White	4 (15%)	4 (17%)	16 (30%)			
Other	0 (0%)	0 (0%)	2 (5%)			

Note. EI: electrical injury; TBI/PTSD: traumatic brain injury/posttraumatic stress disorder; CE Control: Combat Exposed Control. * One-way ANOVA ** Chi-squared test

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Phenomenology of PTSD in EI

Obolsky (2024)

Table 3. MANOVA PCL Total and Cluster Score Differences with SVT Controls

PCL Total and Clusters	EI *M (SD)*	mTBI/PTSD *M (SD)*	CE Controls *M (SD)*	F	η_p^2	Post Hoc
PCL-5 Total Score	53.25 (11.38)	54.91 (18.0)	30.77 (12.9)	35.14***	.42	EI, PTSD>CE, PTSD=EI
Cluster B	2.87 (.81)	3.13 (1.24)	1.73 (.79)	24.18***	.330	EI, PTSD>CE, PTSD=EI
Cluster C	3.1 (.89)	3.15 (1.08)	1.71 (.77)	33.6***	.41	EI, PTSD>CE, PTSD=EI
Cluster D	3.4 (.76)	3.43 (1.09)	2.0 (.94)	27.72***	.36	EI, PTSD>CE, PTSD=EI

Note. EI: electrical injury; TBI/PTSD: traumatic brain injury/posttraumatic stress disorder; CE Control: Combat Exposed Control. *** <.001

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Key Points:

- For at least a subset of EI patients, the presence of psychiatric symptoms during the post-acute phase of injury appears to have a detrimental impact on cognitive functioning.
  - Why cognitive deficits develop in some, but not all survivors remains a mystery
  - Injury characteristics (TBI, cardiac arrest, burns), chronic pain, emotion regulation, life complications all likely play a role
  - Severity of obvious physical injury does **not** correlate with cognitive/emotion regulation symptoms
- Psychiatric sequelae can become a chronic concern that can impact long-term adjustment following EI. Thus, it is imperative that EI survivors receive psychiatric intervention at the onset of emotional symptomatology.

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Workshop Overview

I. The Basics of Electrical Injury (EI)
II. Electrical Injury in Comparison to Traumatic Brain Injury
III. Assessment of Performance and Symptom Invalidity in EI
IV. Factors that Influence Neuropsychological Function after EI
V. EI Myths
VI. Concluding Thoughts

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Myths of Electrical Injury

NO THERMAL BURN = NO INJURY

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Myths of Electrical Injury

THERE MUST BE ENTRANCE/EXIT WOUNDS

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Myths of Electrical Injury

HIGH VS. LOW VOLTAGE HAS SIGNIFICANT IMPLICATIONS FOR COGNITIVE OUTCOMES

- or-

SEVERITY OF OBVIOUS PHYSICAL INJURY CORRELATES WITH COGNITIVE/EMOTION REGULATION SYMPTOMS

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Myths of Electrical Injury

EI SURVIVORS ARE NOT PSYCHOLOGICALLY STABLE TO BEGIN WITH

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Myths of Electrical Injury

ALL DEFICITS ARE RELATED TO COMPENSATION SEEKING

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Workshop Overview

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Summary of Neuropsychological Findings in EI: What we know

- EI is a complex condition that involves diverse (and arguably interrelated) physical, cognitive, and psychological symptoms. It is critical to comprehensive assess each.
- Parameters of the actual EI injury often do not meaningfully relate to postinjury sequelae
  - Don't succumb to the "if/then" fallacy
- Post-EI symptoms are not linear and can differ acutely, post-acutely, and chronically
- Performance and symptom invalidity are an important consideration. Assess them!
- Neuropsychological abnormalities manifest as mild, nonspecific inefficiencies with attention, speed, and motor skills.
  - Severe/global deficits, amnestic memory deficits, and focal impairment are **not** expected
- Psychopathology (particularly PTSD and depression) and pain are highly prevalent post-injury and meaningfully impact neuropsychological function and quality of life

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Summary of Neuropsychological Findings in EI: What remains to be learned

- Does EI result in any direct CNS effect(s)?
  - More advanced imaging technology may help to answer this question
- Are the neuropsychological abnormalities in attention and speed commonly seen in EI reflective of underlying organic dysfunction or other factors?
  - Are EI neuropsychological findings significantly different from PTSD?
  - Is EI neuropsychologically unique after controlling for pain and psychopathology?
- Do post-EI neuropsychological outcomes improve with treatment?
  - Pain treatment may be maximized if multimodal (physical/psychological) (Wesner & Hickie, 2013)
  - Type and timing of effective post-injury psychological interventions
  - Heterogeneity in response often requires tailored rehabilitation treatment (Heilbronner & Pliskin, 1999)

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BEST PRACTICES IN CARE OF POST-ACUTE ELECTRICAL INJURY SURVIVORS

- Optimal treatment involves a team to clinically disentangle and pursue proper diagnosis and treatment
  - Cognitive Issues- Neuropsychological Evaluation
  - Physical Rehabilitation- Physiatrist
  - Pain Complaints- Pain Specialists
  - Emotion Regulation- Psychiatrist
  - Adjustment to Illness- Health Psychologist
- Ultimate goal: Return to work

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BEST PRACTICES IN CARE OF POST-ACUTE ELECTRICAL INJURY SURVIVORS

- *Is the person legitimate in their complaints?*
- *Is there a brain injury + electrical injury?*
- *Is there cognitive impairment?*
- *Presence of PTSD-emotional dysregulation?*
- *Does pain affect cognitive and emotional function?*

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Return to Work

Return to Work After Low Voltage Electrical Injury

Kirstin Theman, BSc,*† Jennifer Singerman, BSc,*† Manuel Gomez, MD, MSc, CTBS,*† Joel S. Fish, MD, MSc, FRCS(C)*†

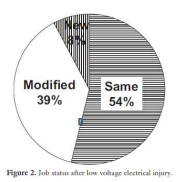

Figure 2. Job status after low voltage electrical injury.

Table 6. Return to work

	Electrical Contact n = 25 (62.5%)	Electrical Flash n = 15 (37.5%)	All Patients n = 40 (100.0%)	P*
Attempted	14 (56.0)	9 (60.0)	23 (57.5)	0.727
Successful	6 (24.0)	7 (46.7)	13 (32.5)	0.197
Same job	4 (16.0)	3 (20.0)	7 (17.5)	0.390
Modified job	2 (8.0)	3 (20.0)	5 (12.5)	0.725
New job	0 (0.0)	1 (6.7)	1 (2.5)	0.335

*Chi-square test between electrical contact and electrical flash values.

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THANK YOU!

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